Explainer: The difference between radiation and radioactivity

December 9 2013, by Martin Boland

Don’t be confused: here’s the difference between radiation and radioactivity. Credit: Mob Mob

On the weekend, a tank of radioactive material leaked from the closed Ranger uranium mine in the Northern Territory. While this has prompted concerns about the health of the surrounding Kakadu National Park, this is a good chance to also clear up the differences between "radioactivity" and "radiation".

Radioactivity and radiation are often used interchangeably, but they describe different (yet related) processes.

But before going into this difference, it's useful to understand what atoms are and a few concepts about how they behave.

An atom is the smallest particle that can be described as a chemical. Smaller particles aren't chemicals in the same way that wheels, windscreens and seats aren't cars – they are parts of them, but you need a few to make the whole.

At the centre of each atom is a nucleus, containing a number of protons (positively charged particles). The number of protons determines what chemical the atom is. All carbon nuclei contain six protons – it is what defines them as carbon nuclei. Five protons would be a boron atom, seven protons a nitrogen atom.

The nucleus also contains a number of neutrons (particle with no charge). Atoms of the same chemical can have different numbers of neutrons. Some 99% of carbon atoms have six neutrons, when added to the six protons this gives an atomic mass of 12.

Some carbon atoms have more or fewer neutrons – seven neutrons makes carbon-13 and eight for carbon-14. The nuclei of carbon-12 and carbon-13 are stable, but carbon-14 is radioactive and is the basis of radiocarbon dating.

Atoms of the same chemical with different numbers of neutrons are known as isotopes.

Surrounding the nucleus are very small negatively charged particles called electrons. These are held in place (called orbitals) by their attraction to the positively charged nucleus. An atom contains as many electrons as protons.

Adding or removing an electron from the atom results in a charged particle, called an ion. Ions can react very differently to atoms. A chlorine atom is very reactive and dangerous; a chloride ion is part of table salt. This becomes important when talking about ionising radiation later.

So, what is radioactivity?

Radioactivity is the term given to the breaking-up (decay) or rearrangement of an atom's nucleus. Decay occurs naturally and spontaneously to unstable nuclei. This instability is usually caused by a mismatch between the number of protons and neutrons.

Radioactive decay can occur in several ways, with the more common ones being:

- spontaneous fission: also known as "splitting the atom" as the nucleus breaks into two parts
- neutron release: a neutron is ejected from the core of the atom
- alpha decay: the nucleus releases an alpha particle (a helium-4 nucleus) consisting of two neutrons and two protons
- beta decay: the nucleus ejects an electron (or a positron). Note: this is not the same as an electron being removed from orbitals around the nucleus
- gamma decay: the protons and neutrons within the nucleus rearrange into a more stable form, and energy is emitted as a gamma ray.

Neutron release, alpha and beta decay are all accompanied by the release of a particle. It is the particle (or the gamma ray in gamma decay) that is the "radiation" associated with radioactivity.

Radioactivity is the decay or rearragement of an atom’s nucleus. Credit: Michael Kappel

What is a 'half-life'?

Let's say we have 4,000 coins and we want to flip them all, which will take (for the sake of the argument) one minute. All of those that land heads are thrown away. By the law of averages, we should have 2,000 coins (half) remaining.

If we then take another minute to flip all of those coins and discard the heads, we will be left with 1,000 coins. And again, taking another minute to flip the 1,000 coins, we will be left with 500 coins.

You'll notice we take the same length of time to flip all the coins, no matter how many of them there are.

In the case of radioactivity, this time is not an artificial constraint, but a fundamental property of each nucleus – that in a given time, it has a 50/50 chance of spontaneously decaying. The name given to the length of time it takes for half the atoms in a sample to decay is called the "half-life".

The half-life of an isotope is the same for all nuclei of that type (all carbon-14 nuclei have a half-life of about 5,750 years and all carbon-15 nuclei have a half life of about 2.5 seconds).

If we perform the coin flip ten times we will be left with four coins – one thousandth of the starting number. This is important because it is considered that after ten half-lives there is a negligible amount of material remaining.

If a material has a long half-life (such as uranium-238's 4.5 billion years half-life – about the age of the Earth), it is not very radioactive. A material with a short half-life (polonium-210's 138 days) is very radioactive.

What's the difference between radioactivity and radiation?

As we have seen, radioactive decay is a property of a particular nucleus. In comparison, radiation is a possible consequence of many processes, not just radioactivity.

Radiation is the term given to a travelling particle or wave and can be split into three main types:

- non-ionising radiation: essentially the low-energy parts of the electromagnetic spectrum. This includes all the light you see,

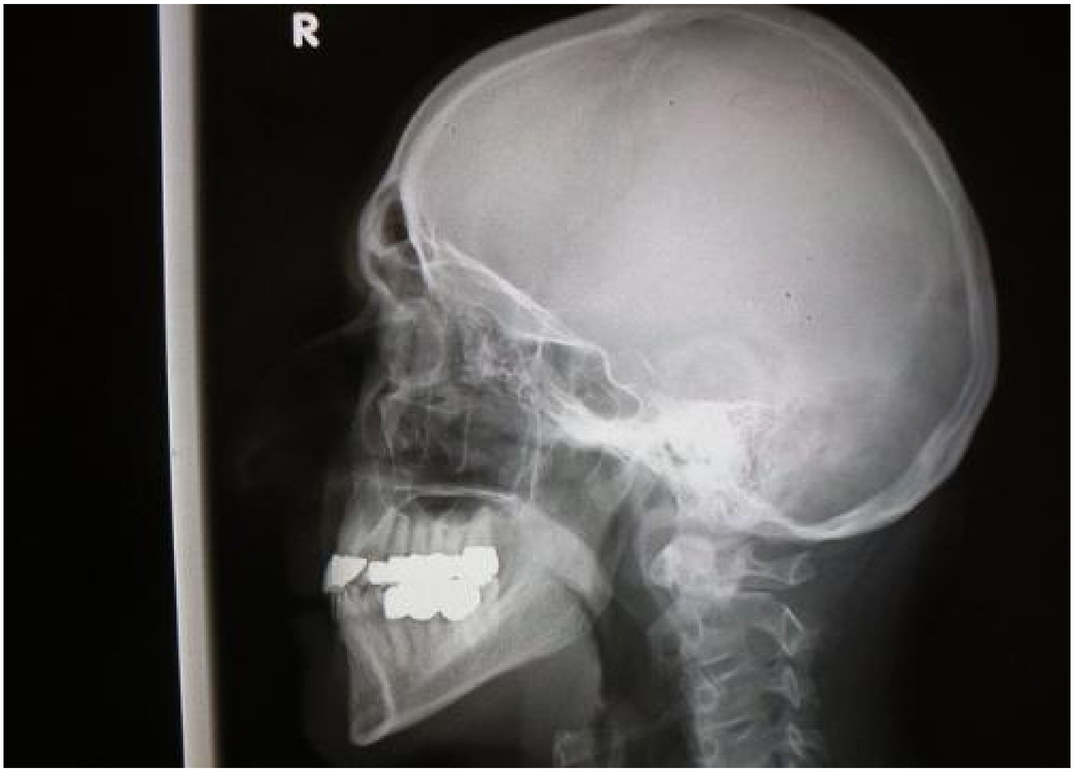
radio waves (also known as microwaves – as in the oven) and infrared ("heat" radiation). Ultra violet falls into the high energy end of this category.
- ionising radiation: radiation that can remove an electron from its orbital
- neutrons: free neutron particles that can collide with other atoms.

Non-ionising radiation is mostly damaging in obvious ways. Exposure to microwaves or infrared waves causes susceptible materials to heat up. Alternatively, ionising radiation can be less obvious but, by changing an atom into a more reactive ion, can create longer lasting damage.

Ionising radiation falls into two main forms:

- high-energy electromagnetic radiation: including X-ray and gamma rays
- particle radiation: alpha and beta particles.

These different forms of ionising radiation differ in their capacity to do damage and their ability to penetrate materials.



X-Ray is a form of high-energy electromagnetic radiation. Credit: Erich Ferdinand

Ionising electromagnetic radiation

X-rays and gamma rays are penetrating, ionising radiation and are are essentially the same thing. (The difference in terminology is usually that gamma rays come from nuclear decay, while X-rays come from electron orbitals.)

These wavelengths of electromagnetic radiation contain enough energy to push an electron out of its orbit around the atom – yet again forming an ion. They are stopped by very dense materials such as lead or large amounts of earth or concrete.

Particle radiation

Particle radiation is potentially very harmful, but is relatively easy to block.

Alpha particles, with two neutrons and two protons, are essentially helium ions. These can strip the electrons from another atom in order to become helium atoms. Beta particles are simply free electrons that can be captured by atoms just like any other electron.

Luckily, protection from these is reasonably easy. Alpha particles are blocked by a piece of paper, and beta particles by a few millimetres of metal or an equivalent amount of plastic.

Neutrons are more penetrating and so are potentially more dangerous. They cause damage by being captured by the nucleus of an atom. This can cause the atom to break in two (fission) or undergo another decay process (known as transmutation).

In either case, the original atom (say a nitrogen atom) is changed to become a different type of atom (in this case, carbon-14). The new atom will have different chemical properties and therefore could act as a poison, or for building materials change their physical properties.

Neutrons are either slowed down or captured safely by materials such as graphite or compounds containing lots of hydrogen (such as tap water!).

All of these forms of radioactivity and radiation are naturally occurring. They make up what is known as background radiation. The web comic xkcd gives a good visual representation of what those numbers look like.

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